Storm Surge and the Future of the Houston Ship Channel

By Jim Blackburn, SSPEED Center, Rice University
Excerpted from work-in-progress with Amy Jaffe, Council on Foreign Relations

The Houston Ship Channel and Galveston Bay are home to eight major refineries and over 200 chemical plants producing a variety of plastics and other synthetic products. This industrial infrastructure provides about 12% of U.S. refining capacity, produces about 27% of the nation's jet fuel and an even larger percentage of military-grade jet fuel, about 13% of the nation's gasoline, and about 25% of the U.S. production of ethylene/propylene. This is a key region for U.S. national security as well as for the Texas and Houston-area economies. Unfortunately, this petrochemical complex is at significant risk of long-term catastrophic failure due to the potential impact of hurricane storm surge.

Over the last 100 years, severe hurricanes with substantial surge have missed the Houston region. Galveston was destroyed by a major hurricane in 1900, about the time that oil and gas was discovered on the Texas coast. The major development of the Houston Ship Channel industrial complex lagged behind that oil discovery in Spindletop by at least two decades and experienced major growth and expansion before and after World War II. To date, the largest surge recorded up the Houston Ship Channel was from Hurricane Ike in 2008 and Hurricane Carla in 1961, and neither of those storms generated more than about thirteen to fourteen feet of surge up the channel, a level that can generally be accommodated by these industries.

The Severe Storm Prediction, Education and Evacuation from Disaster (SSPEED) Center at Rice University began studying the vulnerability of the Houston Ship Channel industrial complex after

Hurricane Ike. Ike was "only" a category 2 storm but generated a storm surge much larger than would be the case with the typical category 2 storm. Fortunately, Ike came inland across Galveston Bay with the "dirty side" of the storm – the area with the largest surge – being to the east of Galveston Bay. Ike basically missed the Houston industrial complex, with the most serious industrial damage occurring east of Houston in the Port Arthur and Orange, Texas, industrial areas, including inundation of the Invista Chemical Plant, parts of which were closed for upwards of one year after Ike.

One of the first evaluations undertaken by the SSPEED Center was to determine the vulnerability of the Houston Ship Channel industrial complex to a reasonably foreseeable storm surge. It was determined that a storm coming ashore south of Galveston Island would generate a major surge event into Galveston Bay due to the onshore winds on the "dirty side" of the storm. Modeling was conducted of a storm like Ike with an increase of 15% in the wind speed (about 125 mph sustained winds) with the hurricane force winds extending out 40 miles from the center as was the case with Hurricane Ike. It is worth noting that this expanded hurricane wind field has been observed in more recent storms fueled by hotter water temperatures in the Gulf of Mexico, the Caribbean Sea and the Atlantic Ocean. Particularly notable and worrisome from a surge perspective were Hurricanes Irma and Maria which were category 4-5 storms with hurricane force winds extending out to about 80 miles from the center. These are the storms of the future that represent a very real danger for ship channel industries.

It is important to note that these "new" storms are different from our historical hurricanes. Storms such as Harvey, Maria and Irma are behaving in ways that would have been considered impossible by many

observers. SSPEED Center has been criticized for modeling storms with greater surge than has been seen in Galveston Bay for the last 100 years. However, it is worth noting that rainfall such as that brought by Hurricane Harvey with over 45 inches in four days had also never been seen prior to 2017. We don't like to talk publicly about climate change in Texas and Houston, but it is and will be a factor in our future. The sooner we recognize this and incorporate the best thinking that we can access about climate change, the better.

SSPEED Center Hurricane Modeling Results

The results of the SSPEED Center's modeling is shown in Figure 1. Here, the surge was determined using the ADCIRC computer model that tracks storms from inception to landfall. As can be seen, a storm about 15% larger than Ike coming inland on the south end of Galveston Island generates a surge of about 20 feet at the City of Galveston, overtopping the sea wall which is 17 feet MSL and the Texas City levee system which is on the southeastern corner of the mainland, flooding the 832,000 barrels of production located there. Further north, the surge reaches 22 to 23 feet in the area of the Bayport Industrial complex and reaches approximately 25 feet in height into the channel itself which is home to about 1.4 million barrels of refining capacity.

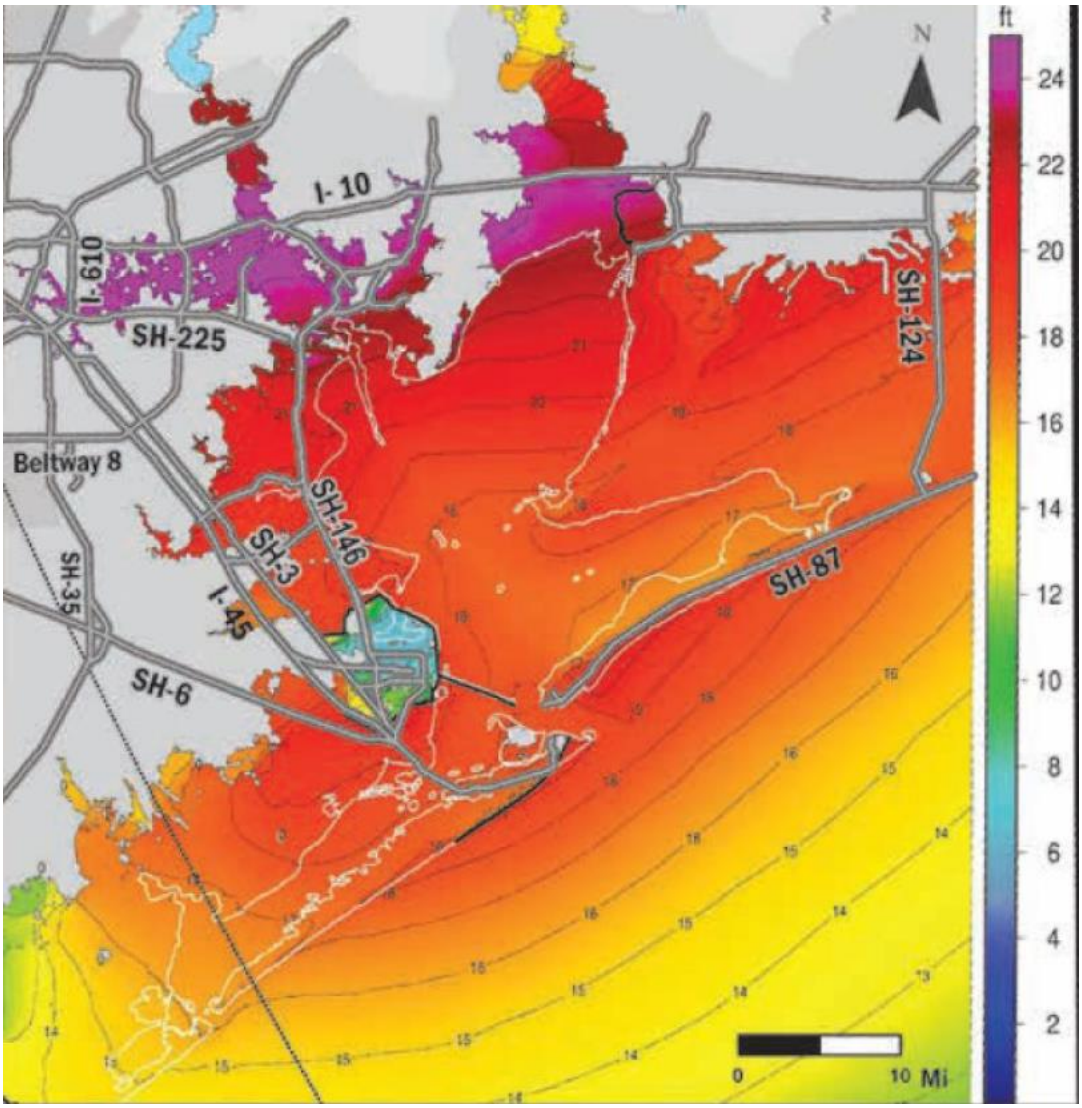

Figure 1. The elevation of the surge from a storm such as Ike but with 15% stronger winds coming ashore near San Luis Pass, representing a reasonable risk storm event for planning purposes. The Houston Ship Channel lies between IH-10 and SH 225 in the upper left of the diagram. Texas City is the area shown in blue behind the levee. The Galveston Bay shoreline is indicated by the white line. Graphic content courtesy of SSPEED Center and rendered in GIS by Christina Walsh.

The results of such surge flooding would be devastating. The damages to Texas City refineries and chemical plants and Bayport industrial district plastic plants would be extensive. Approximately

2200 of 4400 storage tanks on the Houston Ship Channel will be inundated to some degree, along with most of the refinery and plastics production complex. All of the piping and low-lying equipment will be flooded with salt water. All of the flooded electrical systems will likely fail and need replacing. Process units will be surrounded if not invaded by surge-flooding.

According to work undertaken by Dr. Jamie Padgett of the SSPEED Center, some percentage of the flooded tanks can be expected to fail, either by being lifted off of their foundations or by being crushed by the water or penetrated by debris. Dr. Padgett's team estimated that a 24-foot surge event could lead to the release of at least 90 million gallons of oil and hazardous substances, a huge amount. It would also cripple the industrial production for months if not years, threatening the United States economy and certainly raising substantial concerns about transportation fuel availability.

To further put this potential release into perspective, the Deepwater Horizon spill offshore of Louisiana generated about 210 million gallons of crude oil whereas the Exxon Valdez disaster generated about 12 million gallons of oil. In both cases, the spill was into the open waters of either the Gulf of Mexico or Prince William Sound. With a spill on the Houston Ship Channel, the oil and hazardous substances would be disgorged into the marshes and contained waters of Galveston Bay after entering and contaminating adjacent neighborhoods. The bay would be contaminated for decades. The result would likely be among the worst disasters in United States history.

The need for some type of structure to protect these refineries and chemical plants is clear because many non-structural alternatives

such as buy-outs and relocation are simply not feasible. The real issue is what type of protection should be offered and to what level of protection? The 25-foot surge event that has been forecast does not include sea level rise or the effects of climate change on the storms of the future. With three feet of sea level rise and a moderate increase in storm size, such a future storm could exceed thirty feet of surge. The potential of such a future storm needs to be balanced against the fact that a surge greater than fifteen feet has not occurred to date, a point that the SSPEED Center team often encounters in discussions with industrial audiences throughout the region.

The feedback on these modeling results has been instructive. First, there is a reluctance in many circles to believe these results. A commonly-heard industrial response is that they doubt the validity of the modeled results because such a storm surge has not been experienced in past storm events. These industries, for the most part, are protected to the 100-year flood level (as indicated on flood plain maps issued by the Federal Emergency Management Agency). On the other hand, what is "reasonably foreseeable" is changing every month as we learn more about climate change, and the publications grow. If we at SSPEED Center had modeled the rainfall of Hurricane Harvey before it occurred, we would have had a similar if not stronger reaction. Harvey, of course, happened.

Similarly, the modeling has been criticized as making improbable assumptions, namely selecting a storm having the characteristics of Ike but with 15% higher wind speeds. The hurricane-force wind field from Ike extended out 40 miles, a large distance. At least one scientist with solid credentials questioned that a wind field that large could be maintained with the higher wind speeds of a Category 3 storm. This

issue was arguably rendered moot by Hurricane Maria, a category 5 storm, due to the fact that the hurricane-force wind field extended out almost 80 miles from the center, a large distance that is a critical factor on surge generation on areas such as the upper Texas coast and Louisiana with large continental slopes offshore.

Climate change is at the heart of the question of what size storm we should anticipate and include in our plans, our regulations and our operating procedures. We are seeing storms that are unprecedented. These are not yet reflected in flood plain maps prepared by the Federal Emergency Management Agency. They are not generally acknowledged within the industrial community. The engineering community lacks effective tools to address this issue. Yet these storms are occurring. Central to preventing a huge disaster on the Houston Ship Channel is addressing the discrepancy between perceived and real risk.

Protecting the Galveston Bay Region

To date, two alternatives that are receiving serious scrutiny have been designed to protect the Galveston Bay region, including Texas City, Bayport and the Houston Ship Channel. These are (1) the so-called Ike Dike or Coastal Spine and (2) the Galveston Bay Park Plan. These are discussed sequentially.

The Ike Dike, also referred to as the coastal spine, was designed by Dr. William Merrell of Texas A&M Galveston in the aftermath of Hurricane Ike. The Ike Dike is a levee structure approximately 17 feet high that runs along the coast northward from San Luis pass at the southern end of Galveston Island where it connects with the existing Galveston sea wall. Two gate structures – a navigation gate and a tidal-flow gate structure – span the approximately two-mile-wide and 30- to 60-feet deep pass between Galveston and the Bolivar Peninsula. On

Bolivar, the 17-foot dike structure is continued northward to its terminus near High Island. A conceptual diagram of the Corps of Engineers' "coastal spine" is shown in Figure 2. A backside levee around the City of Galveston is also added due to backside flooding potential within the City.

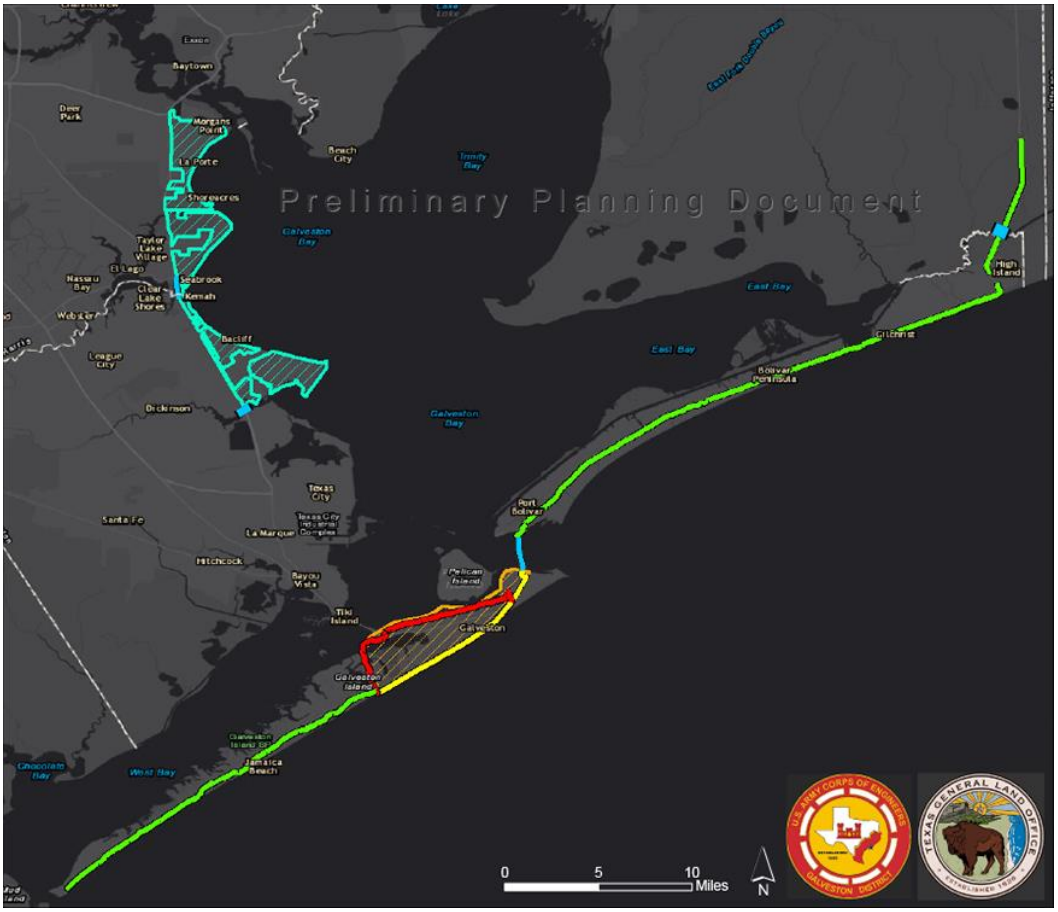

Figure 2. The coastal spine alternative as set out in the joint study by the U.S. Army Corps of Engineers and the General Land Office of the State of Texas. The green line along the coast is a dike structure and the yellow line is the existing sea wall at the City of Galveston. The blue line between the yellow and green lines crosses the two-mile open water pass called Bolivar Roads. The red line is a backside levee for the City of Galveston and the cross-hatched area is designated for non-structural controls. Graphic from the U.S. Army Corps of Engineers and the General Land Office, State of Texas.

The coastal spine shown above in Figure 2 was the subject of a Draft Environmental Impact Statement released by the U.S. Army Corps of Engineers in late 2018. The green line represents the levee which is the bulk of the spine and the blue line includes both a navigation gate and an environmental flow gate. The spine has been met with strong public opposition on the Bolivar Peninsula where concerns arise over the impact to private property and the absence of beach nourishment and protection. Similar opposition has been forthcoming from the environmental community that is concerned about long-term impacts to Galveston Bay due to the circulation and salinity changes attributable to the proposed gate structures which are massive and contain numerous tide gate openings in an attempt to mitigate potential environmental impacts. The cost of this gate structure is from $14 to $20 billion with a completion date estimated to be 2035. At the current time, the coastal spine is proposed to be constructed with federal funding.

There are issues about the effectiveness of the coastal spine in actually protecting the west side industrial complex and the ship channel. Even with the pass into the Gulf of Mexico shut off, sufficient water remains in Galveston Bay to generate a significant surge, depending upon the orientation of the storm. ADCIRC modeling of the impact of a moderate category 3 storm with the characteristics of Hurricane Ike is shown in figure 3. Here, the surge is indicated to rise to about 20 feet in the ship channel and to inundate much of the Bayport Industrial complex on the west side. It is important to note that the U.S. Army Corps of Engineers' methodology did not single out specific, reasonable worst-case storms as did the SSPEED Center's approach. Similarly, the Corps did not identify significant benefits to the Houston Ship Channel from their approach.

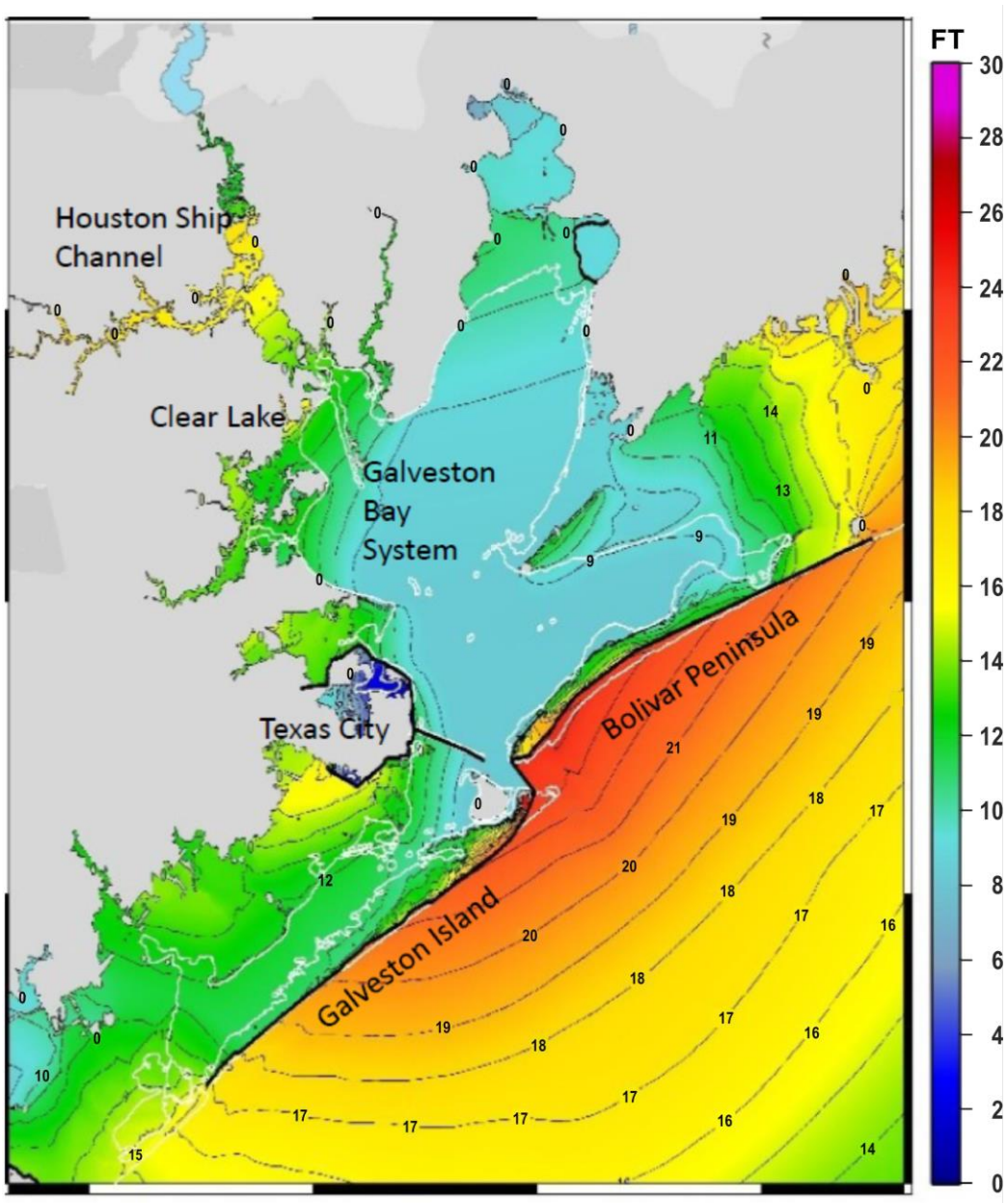

Figure 3. Hurricane surge flooding from a moderate category 3 storm with the characteristics of Hurricane Ike with the coastal spine in place. The Texas City industrial complex is protected by the existing levee, but 12 to 14 feet surge extends inland in the Bayport area and reaches 18 to 20 feet up the Houston Ship Channel. Graphic courtesy of SSPEED Center.

The Galveston Bay Park Plan was developed by the SSPEED Center and is contained within Galveston Bay as shown in Figure 4. Here the

protection would extend from uplands in Chambers County to the east of Baytown, extending down the bay adjacent to the Houston Ship Chanel and then turning west to connect into the existing Texas City levee system. The flood protection levee would be constructed to elevation 25 feet along the edge of the Houston Ship Channel (potentially as part of the proposed widening of the channel), combining navigation enhancement with surge protection. This structure and the associated dredged material disposal sites ultimately would be converted into created wetland reserves and park and open space. This proposal includes both a navigation gate of about 1100 feet in width and at least five small vessel navigation and circulation gates to connect Galveston Bay to Trinity Bay. Additionally, the SSPEED Center is proposing to raise the Texas City levee system to 25 feet from its current 17 feet elevation, raise major roads on the Bolivar Peninsula and West Galveston Island for evacuation purposes and construct a backside levee around the City of Galveston.

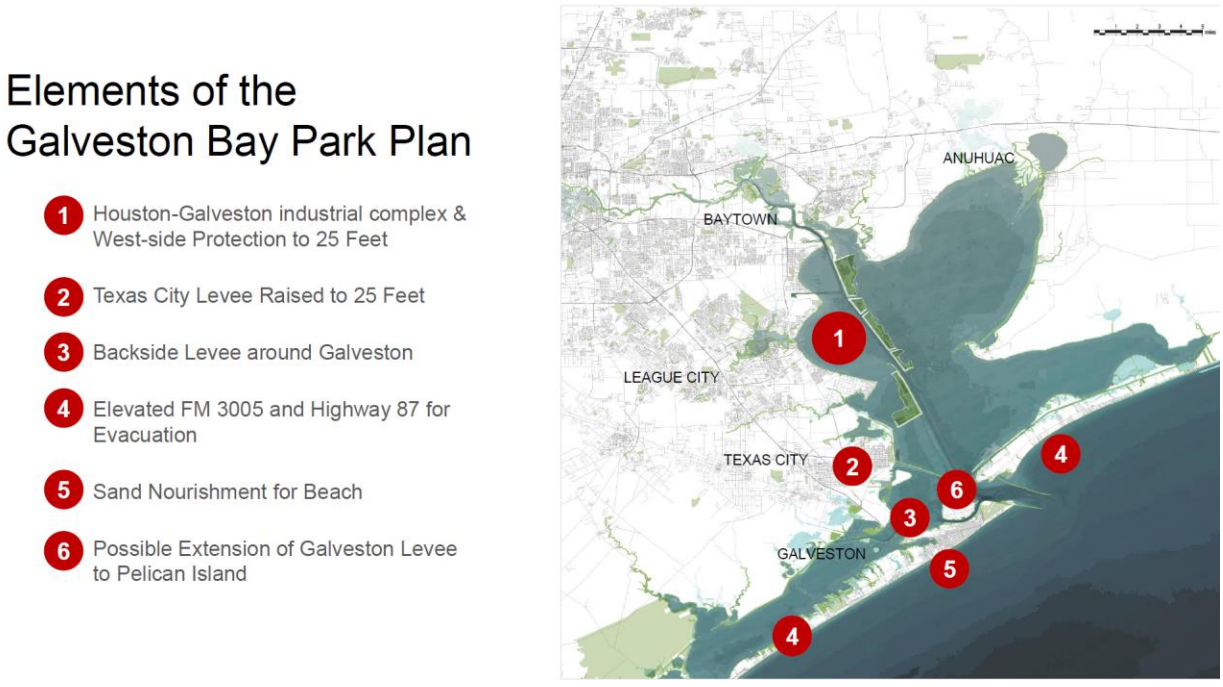

Figure 4. Galveston Bay Park Plan with general location/description of key features. Graphic courtesy of Rogers Partners and SSPEED Center.

As a general statement, the Galveston Bay Park Plan is very effective at protecting the Houston Ship Channel and the Bayport Industrial complex from a Category 3-4 storm with the characteristics of Ike as shown in figure 5. Similarly, Texas City will be protected from such an event with the increase in levee height to 25 feet in elevation. Such a storm would overtop the existing seawall of the City of Galveston unless it were raised to about 22 feet which is depicted in figure 5. The Galveston Bay Park Plan is estimated to cost from $3 to $6 billion and could be constructed in phases with funding from various sources.

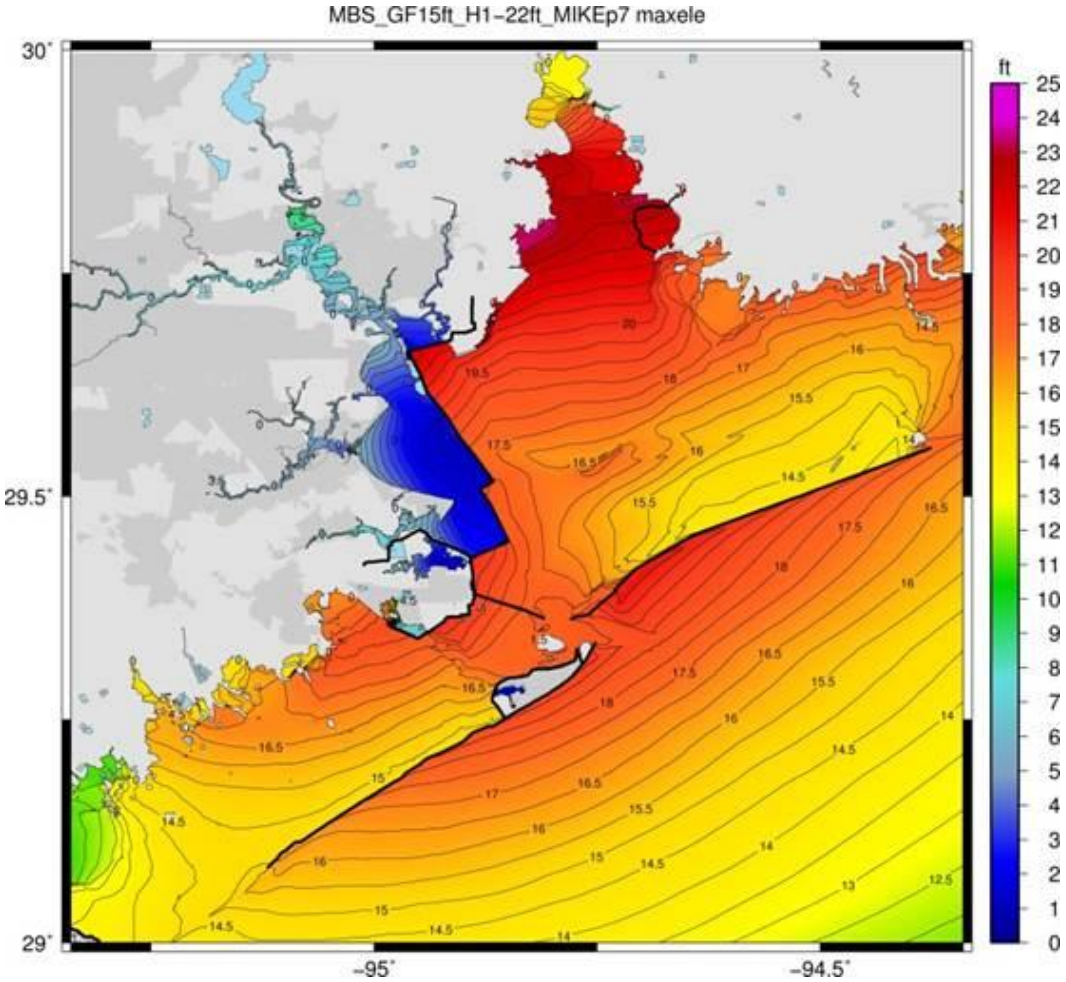

Figure 5. Effectiveness of the Galveston Bay Park Plan in protecting the west side of Galveston Bay from a storm similar to Hurricane Ike with 15% higher wind speeds, making it a category 3-4 storm event.

To date, the Galveston Bay Park Plan has not been evaluated by the U.S. Army Corps of Engineers, although it has been gaining public support. Among the reasons for this support are its relative cost, its flexibility in terms of funding, the construction timing and the lesser environmental impacts. Various entities are evaluating submission of the Galveston Bay Park plan for Corps of Engineers permits.

Another warning note is warranted regarding the size of storm surge for which planning is being undertaken. The Corps of Engineers planning does not directly address the larger storm anticipated by SSPEED Center. The Corps' highly complicated modeling process led them to determine that there were very few dollar benefits associated with protecting the Houston Ship Channel. Indeed, over 50% of their benefits came from protecting the City of Galveston. By contrast, the SSPEED Center's solution is driven by protecting both the industrial complexes and the public on the mainland. SSPEED Center also proposed a ring levee for Galveston, but that was not the major source of the benefits from the SSPEED Center's solution.

Conclusion

A major threat exists to the refining and chemical industrial complex that is based around Galveston Bay. This issue has not received the attention that it should from a national security perspective, from a national economic stability perspective and from an environmental risk perspective. The SSPEED Center's experience in modeling and planning to protect the channel highlights the disconnect between past observations and future likely events being encountered everyday throughout the world with our changing climate. We are facing situations that differ from the past, but we seemingly lack the institutional ability or fortitude to address these future risk and avoid the national security consequences that are foreseen and forewarned.